A STUDY OF HEIGHT TENDENCIES AT THE 500 MB LEVEL

BY

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PREFACE

This paper presents the results of what was originally a study of 36-hour and 3-day height tendencies at the 500 mb level. This study led into further investigation on the relationship between sea level and 500 mb waves. The objectives of tho paper were: first, to determine how these tendencies were correlated with other selected variables at 500 mb; secondly, to determine how far in advance and under what conditions regression equations for determining these tendencies are valid; and thirdly, to study the interdependence of 500 mb and sea level waves with special emphasis on their periodicity.

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TABLE OF SYMBOLS AND ABBREVIATIONS

DTG	Date time group
Fropa	Frontal passage
mb	Millibar
r	Correlation coefficient
S	Standard error of estimate
σ_i	Standard deviation about the arithmetic mean of the variate X_i (i going from 1 to 7)
S.L.	Sea level
$\overline{X}_i$	Arithmetic mean of variate X_i (i going from 1 to 7)
X_1	Height tendency at 500 mb for past 3 days
X_2	Deviation of 500 mb height from the long term monthly normal
X_3	Height tendency at 500 mb for following 3 days
X_4	Temperature change at 500 mb for past 3 days
X_5	Deviation of 500 mb temperature from the long term monthly normal
X_6	Height tendency at 500 mb for past 36 hours
X_7	Height tendency at 500 mb for following 36 hours
Z	Zebra or Greenwich meridian time

I. INTRODUCTION

With the ever increasing number of aircraft flights at higher and higher altitudes and the desire to more closely correlate the prognostic charts for various levels has come the need for more accurate means of forecasting the movement of troughs and ridges at upper levels. The objective of this project was to provide forecasting tools which would aid the prognostication of the 500 mb chart in the vicinity of a single station. The investigation was carried out on a purely statistical basis with no dynamic or kinematic treatment involved.

The 500 mb level was chosen because it is high enough that movements of waves are fairly regular and some of the smaller fluctuations are absent; it is not so high, however, that reports become more scarce due to Radiosonde failures. Other investigators have struggled with this same old meteorological problem of attempting to prognosticate upper and sea level wave patterns as far into the future as possible.

Aime and Johnson [1], who were concerned with making a 3-day prognostic 6-kilometer chart, made the following statement in their paper on the preparation of long range forecasts:

> In general, it is reasoned that in areas where pressures are above normal and where the pressure changes for the past 72 hours have been positive over the same areas, the pressures will fall in the next 72 hours as much as they rose in the last 72 hours. Negative changes and departures from normal are considered in a similar manner.

Since the 6-kilometer and 500 mb levels are quite close to each other, their line of reasoning should also hold for height tendencies at 500 mb. The above rule would work best for troughs and ridges which are symmetrical about their center-line and have no acceleration.

The Krick [5] method of long range forecasting by the use of 'weather types' depends, basically, upon major frontal passages at the surface every 6 days with minor passages every 3 days. It would be logical to assume that trough passages aloft would have approximately the same periods. If these 3 and 6-day periods can be applied at a single station for certain lengths of time and with a reasonable accuracy, at least a start has been made toward the building of forecast tools for the 500 mb level.

The first investigations carried out in this study were more or less checks on the reliability of the two methods mentioned above when applied to a single station. These in turn led to further research to see just how far and with what accuracy tendency equations could be extended. The answer to the last problem appeared to depend to a great extent on the periods of the waves found at the 500 mb level. A desire to find out what effect 500 mb trough passages had on sea level frontal passages and vice versa led to the final study of the relationship between wave periods and ranges at these two levels.

II. SELECTION OF A STATION FOR STUDY AND THE SOURCES OF DATA USED

Columbia, Missouri (station number 445) was selected as the reporting station to be investigated. It is located at Latitude 39N, Longitude 92W and has a station elevation of 785 feet. Columbia was selected because it normally lies in the zone of upper westerlies, is considerably removed from any large body of water, and is far enough from the Rocky Mountains to be free from any 'lee-side' trough effect that might possibly extend as high as the 500 mb level.

The period covered by this study extended from October 1, 1948 through September 30, 1949; however, the greatest portion of the research was carried out for the six months from October through March. This was done because of the greater intensities of troughs and ridges during this period than during the other half-year.

All of the Radiosonde reports used in this study were taken from the Daily Upper Air Bulletins [3] and are unedited data. As a whole the reports appeared to be quite consistent, and there were very few gaps in the research period due to missing data.

The approximate times of sea level trough and frontal passages used in the latter part of this investigation were obtained from the following sources:

1. Postgraduate School Staff Analysis.
2. WBAN Facsimile Transmissions.
3. WBAN Daily Series of Synoptic Charts for January and February of 1949.

III. TECHNIQUE OF INVESTIGATION

1. Formulation of the Tendency Equations

For each of the daily soundings taken at 0300Z and 1500Z the surface pressure and temperature and the 500 mb height, temperature, and wind velocity were recorded over the year to be studied. This data was then further broken down into seven variates which were investigated using strictly statistical procedures. These variates were labeled as follows:

X_1 Height tendency at 500 mb for the past 3 days.

X_2 Deviation of the 500 mb height from the long term monthly normal.

X_3 Height tendency at 500 mb for the following 3 days.

X_4 Temperature change at 500 mb for the past 3 days.

X_5 Deviation of the 500 mb temperature from the long term monthly normal.

X_6 Height tendency at 500 mb for the past 36 hours.

X_7 Height tendency at 500 mb for the following 36 hours.

Wind velocity was omitted because preliminary scatter diagrams revealed that neither West-East nor North-South wind components had any appreciable correlation with the above variates.

The long term monthly normals for Columbia were obtained from Normal Weather Maps, Northern Hemisphere Upper Level [6]. The values given in this series of charts were for pressure and temperature at the 20,000 ft. level and had to be converted to normal heights and temperatures at the 500 mb

level. These conversions were made using tables constructed by Bellamy [2]. Table 1 gives the long term normal heights and temperatures used in this study.

TABLE 1

MONTH	HEIGHT (FT)	TEMPERATURE (C)
January	18200	-22
February	18150	-23
March	18410	-21
April	18610	-19
May	18860	-15
June	19160	- 9
July	19360	- 9
August	19310	- 8
September	19160	- 9
October	18860	-14
November	18560	-18
December	18260	-23

500 mb Long Term Normal Heights and Temperatures for Columbia, Missouri

The Aims and Johnson rule was first tested for 36-hour and 3-day height tendencies on either side of trough and ridge passages at Columbia. This investigation was carried out for the winter season only but should yield comparable results for summer as well. A timegraph of the 500 mb heights was made to facilitate the determination of times of trough and ridge passages. Any wave with a range greater than 200 feet was considered to be significant enough for study. This limitation does not appear to be inconsistent when account is taken of the diurnal variation of 135 feet which was calculated for Columbia for the winter season under consideration. Simple and multiple correlations were run for variates X_1, X_2, X_3, X_6 and X_7, and the corresponding regression equations for height tendencies were formed.

Since the correlation (for troughs and ridges) between the past 36-hour height tendency and the following 36-hour height tendency (X_6 and X_7) was quite encouraging, it was decided to examine all 0300Z winter reports using these same two variates. Only the one time was used in this study in order to eliminate any possible diurnal effect. Actually, this amounted to a test of how closely the waves at 500 mb fit a pattern that has sinusoidal waves and a 3-day period.

Correlations were next made (using <u>all</u> of the data divided into summer and winter seasons) between the past 3-day height tendency and the following 3-day height tendency (X_1 and X_3). This amounted to a test of a sinusoidal wave pattern with a 6-day period.

With the idea in mind that temperature changes at the 500 mb level should give some indication of the type of advection taking place at higher levels, the past 3-day temperature change was correlated with the following 3-day height tendency for all winter reports (X_3 and X_4).

Finally, height tendencies for the following and past 36 hours and 3 days were correlated with the deviations of the heights from the long term monthly normals (X_1, X_3, X_6, and X_7 against X_2). The 3-day tendencies were also correlated with the deviations of temperature from the long term monthly normals (X_1 and X_3 against X_5). The results of these tests were found to be good enough to warrant multiple correlations between these variates. Simple and multiple regression equations were formed for any variates which had a correlation coefficient greater than 0.50.

2. Relationships Between Sea Level and 500 mb Waves

In order to see how the waves at sea level were related to those already studied at 500 mb, a time-graph of sea level pressures was added to the one constructed previously for 500 mb heights. This made it possible to distinguish which troughs and ridges were clearly defined at both levels and which ones appeared at one level only.

It was decided to work with half-waves because, in most cases, the time from trough to ridge was considerably different from the time from the same ridge to the next trough. A complete list was made of all half-waves; they were tabulated as to the time of passage of their mid-period. Thus, by giving the time of each mid-period and the semi-period of each half-wave (to the nearest 12 hours) it was possible to identify the time of beginning and ending of all half-waves, both at sea level and at 500 mb.

The next step was to tabulate the range of each sea level half-wave in millibars and the range of each 500 mb half-wave in feet (range being the pressure or height difference between trough and ridge or ridge and trough of each half-wave).

In all cases where there was definite evidence that a sea level half-wave could be identified with a particular half-wave aloft, the lag between the two mid-periods was computed. If the lag between the mid-periods at the two levels was greater than 30 hours the half-waves were considered to be unrelated. A further limitation was imposed in that a sea level trough or frontal passage had to be distinguishable at one end of the half wave. Surface maps were used to determine the approximate times of these passages.

Thus, a 'positive' lag means that the mid-period of the sea level half-wave passed Columbia before the mid-period of the 500 mb half-wave. The opposite order of passage corresponds to 'negative' lag.

A complete list of all half-waves studied during the winter season is given in Tables 2 through 7.

TABLE 2

Mid-Period DTG	Sea Level Semi-Period (Days)	500 mb Semi-Period (Days)	Lag (Hours)	Sea Level Range (mb)	500 mb Range (Ft)	Remarks
050300Z		5.0	-12		1230	
051500	4.0			27		Fropa 071500Z
081500	2.0	2.0	0	12	920	
100900		1.5	- 6		520	
101500	2.0			20		Fropa 111500
120300	1.0			23		
122100		3.5			930	
130300	1.0			3		Fropa 131800
132100	0.5			10		No effect aloft
150300	2.0		+ 24	19		
160300		3.0			760	Fropa 161800
162100	1.5		+ 30	25		
180300		1.0			410	
180300	1.5		+ 18	13		
182100		0.5			30	Fropa 191500
192100	1.5	1.5	0	4	120	
210900	1.5	1.5	0	4	440	Fropa 220000
230900	2.5		+ 6	11		
231500		3.0			740	
272100	6.5		+ 6	18		
280300		6.0			460	Fropa 310000
311500		1.0	- 6		140	
312100	1.5			4		

Comparison Between Sea Level and 500 mb Half-Waves for October, 1948

TABLE 3

Mid-Period DTG	Sea Level Semi-Period (Days)	500 mb Semi-Period (Days)	Lag (Hours)	Sea Level Range (mb)	500 mb Range (Ft)	Remarks
030900Z	3.5	4.5	0	24	950	Fropa 050600Z
060900	2.5		+ 12	32		
062100		2.5			880	
080900	1.5		+ 18	13		
090300		2.0			1180	Fropa 090000
100900	2.5		+ 18	12		
110300		2.0			920	
120300	1.0		+ 12	8		
121500		1.0			400	Fropa 121800
130300	1.0		+ 6	12		
130900		0.5			550	
140300	1.0	1.0	0	7	60	Tropa 041200
142100	0.5		+ 6	1		
150300		1.0			270	
152100	1.5		+12	16		
160900		1.5			580	Fropa 161800
170300	1.0		+ 6	11		
170900		0.5			290	
181500	2.0		+ 6	22		
182100		2.5			1310	Lowpa 190600
201500		1.0	+ 6		950	
202100	2.5			25		
222100		3.5	-12		290	
230900	2.5			12		Tropa 241200
242100Z	0.5		+ 6	1		
250300		1.0			330	
251500	1.0		+ 18	3		
260900		1.5			370	Fropa 260000Z
272100	3.5		+12	20		
280900		2.5			650	
292100	0.5		+ 12	3		
300900		1.5			120	Tropa 301200

Comparison Between Sea Level and 500 mb Half-Waves for November, 1948

TABLE 4

Mid-Period DTG	Sea Level Semi-Period (Days)	500 mb Semi-Period (Days)	Lag (Hours)	Sea Level Range (mb)	500 mb Range (Ft)	Remarks
302100Z	1.5		+12	5		
010900		0.5			170	
020900	1.5	1.5	0	9	240	Tropa 030300
030900	0.5		+12	2		
032100		1.5			440	
041500	2.0		+18	Missing		
050900		1.5			1140	Fropa 051200
060300	1.0		+ 6	Missing		
060900		0.5			390	
062100	0.5			5		Tropa 070000
070900	0.5			8		Surface only
071500		2.0	-12		340	Tropa 081200
080300	1.0			2		Aloft
091500	2.0	2.0	0	19	720	
110900	1.5	1.5	0	29	300	Fropa 120600
130300	2.0	2.0	0	9	760	
142100	1.5		+18	9		
151500		3.0			460	Fropa 151200
161500	2.0		+18	25		
170900		0.5			20	
182100		2.5	-12		900	
190900	3.5			29		Fropa 210600
220300		4.0	-6		960	
220900	2.5			28		
240900	1.5		+12	3		
242100		1.5			470	Tropa 250000
251500	1.0		+30	16		
262100		2.5			480	
271500	3.0		+30	42		
282100		1.5			770	Fropa 290000
292100	1.5		+ 6	35		
300300		1.0			480	
310300	1.0	1.0	0	7	30	Fropa 311200
312100	0.5	0.5	0	1	130	

Comparison Between Sea Level and 500 mb Half-Waves for December, 1948

TABLE 5

Mid-Period DTG	Sea Level Semi-Period (Days)	500 mb Semi-Period (Days)	Lag (Hours)	Sea Level Range (mb)	500 mb Range (Ft)	Remarks
011500Z		1.0			320	
021500	3.0			20		Fropa 040600Z
030300		2.0			360	
042100		1.5			710	Tropa aloft
050900	2.5		+ 30	12		
061500		2.0			990	
071500	2.0		+ 30	13		
072100		0.5			200	Fropa 090000
090900		2.5	-6		590	
091500	2.0			31		
130300	5.0		+ 18	30		Fropa 151800
132100		6.5			850	
161500	2.0		+ 24	26		
171500		1.0			170	
180300	1.0		+ 12	21		
181500		1.0			630	Fropa 190000
190900	1.5		+ 12	31		
192100		1.5			670	
202100	1.5		+ 6	24		
210300		1.0			Missing	Fropa 211200
220300	1.0		+ 6	14		
220900		1.5			Missing	
230900	1.5		+ 12	17		
232100		1.5			90	Fropa 240000
242100	1.5		+ 6	21		
250300		1.0			70	
262100	2.5		+ 18	24		
271500		4.0			1130	Fropa 280000
290300	2.0		+ 24	37		
300300		1.0			440	
Data missing for the last trough of the month						

Comparison Between Sea Level and 500 mb Half-Waves for January, 1949

TABLE 6

Mid-Period DTG	Sea Level Semi-Period (Days)	500 mb Semi-Period (Days)	Lag (Hours)	Sea Level Range (mb)	500 mb Range (Ft)	Remarks
Data missing for the first half of the ridge						
030300	2.0		+18	26		
032100		1.5			500	Fropa 040000
041500	1.0		+12	11		
050300		1.0			40	
052100	1.5		+12	13		
060900		1.5			250	Fropa 061200
062100	0.5		+18	9		
071500		1.0			430	
072100	1.5		+18	12		
081500		1.0			170	Fropa 081500
090300	1.0		+ 6	18		
090900		0.5			60	
092100	0.5	0.5	0	5	170	Fropa 100600
100900	0.5		+24	10		
110900		2.5			870	
112100	2.5		+24	21		
122100		0.5			100	Fropa 130000
130900		0.5	- 6		50	
131500	1.0			17		
141500Z	1.0		+18	17		
150900		2.5			830	Fropa 150000
160300	2.0		+24	20		
170300		1.0			860	
180300	2.0		+12	12		
181500		2.0			140	Fropa 191200
192100	1.5		+ 6	16		
200300		1.0			150	
210900	1.5		+ 6	8		
211500		2.0			210	Fropa 220000
221500	1.0		+12	3		
230300		1.0			340	
232100	1.5		+ 6	13		
240300		1.0			540	Fropa 241500
250300	1.0	1.0	0	14	290	
260900	1.5		+12	11		
262100		2.5			460	Fropa 271200

Comparison Between Sea Level and 500 mb Half-Waves for February, 1949

TABLE 6

Mid-Period DTG	Sea Level Semi-Period (Days)	500 mb Semi-Period (Days)	Lag (Hours)	Sea Level Range (mb)	500 mb Range (Ft)	Remarks
272100	1.5		+18	14		
281500		1.0			170	

Comparison Between Sea Level and 500 mb Half-Waves for February, 1949 (Continued)

TABLE 7

Mid-Period DTG	Sea Level Semi-Period (Days)	500 mb Semi-Period (Days)	Lag (Hours)	Sea Level Range (mb)	500 mb Range (Ft)	Remarks
010900	1.5		+ 6	7		
011500		1.0			100	Tropa aloft
022100	1.5	1.5	0	3	440	
041500	2.0		+12	18		
050300		3.0			440	Fropa 051500
061500	2 .0		+12	17		
070300		1.0			420	
080900	1.5		+12	18		
082100		2.5			660	Fropa 090000
Three days data missing and two days garbled						
161500	2.0		+24	15		
171500		1.0			280	Fropa 171200
180900	1.5		+24	16		
190900		2.5			640	
201500	3.0		+18	34		
210900		1.5			690	Lowpa 220000
222100	1.5		+ 6	16		
230300		2.0			520	
240900	1.5		+ 6	12		
241500		1.0			120	Fropa 250000
250900	0.5		+12	14		
252100		1.5			200	
260900	1.5		+18	19		
270300		1.0			540	Fropa 270000
280900	2.5		+ 6	17		
281500		2.0			700	
300900	1.5		+ 6	15		
301500		2.0			870	Fropa 310000

Comparison Between Sea Level and 500 mb Half-Waves for March, 1949

IV. RESULTS AND CONCLUSIONS

1. Formulation of the Tendency Equations

In the formulation of the tendency equations, all computations dealing with heights were carried out in hundreds of feet; this same unit was used for all height variates in the resulting regression equations. In like manner, all work involving temperatures was done in degrees Centigrade.

The results of the test of the Aime and Johnson rule were highly satisfactory. The correlation obtained between the past and following 36-hour height tendencies (X_6 and X_7) for trough and ridge lines in winter indicates that this rule may be used as a reliable forecasting tool. However, caution must be used in applying this rule to systems that are changing rapidly in intensity.

The addition of the variate X_2 (deviation of height from the long term monthly normal) raised the correlation coefficient even further. The multiple regression equation for the determination of X_7 from known values of X_2 and X_6 at trough and ridge lines should be a valuable aid for 36-hour prognostication of the 500 mb height at Columbia. It is probably safe to assume that the same equation will hold reasonably well for nearby stations. Similar statistical studies at other stations should yield tendency equations that would, when used together, improve large areas of the prognostic chart under these particular conditions. Table 8 gives the results of the test of the Aime and Johnson rule for 36-hour tendencies.

As was to be expected, the test of the above rule applied to 3-day instead of 36-hour tendencies yielded slightly poorer results. The addition of variate X_2 (deviation of height from the long term monthly normal) gave a multiple correlation which was slightly better. It is felt, however, that the resulting regression equation provides a definite forecast tool. Table 9 gives the results of the test of the Aime and Johnson rule for 3-day tendencies.

The correlation between X_6 and X_7 for all winter-time 0300Z reports, regardless of position relative to troughs and ridges, was not strongly significant. This would seem to indicate that, while there is a definite trend for 500 mb waves to have a sinusoidal wave pattern with a period of 3 days, any attempt to use this pattern for prognostication would not be warranted. This does not imply that the basic assumption of the 'weather type' forecast method is invalid. This method does not rigidly fix the period of surface frontal passages at 3 days nor does it require that all waves be sinusoidal. The results of this test are given in Table 10.

The correlation between past and following 3-day height tendencies (X_1 and X_3) for all winter data was, surprisingly enough, as good as the one obtained for the 36-hour tendencies during the same season. Once again, this indicates that a trend for 6-day waves is present at 500 mb; however, the use of this period is also not warranted for accurate prognostication.

The addition of variate X_2 (deviation of height from the long term monthly normal) gave a multiple correlation which was considerably more significant. A multiple correlation of the following 3-day height

tendency against the temperature deviation from the long term monthly normal and the height deviation from the long term monthly normal (X_3 against X_2 and X_5) was found to yield a correlation coefficient identical to the one obtained for X_3 against X_1 and X_2. The results of these tests are given in Table 12.

The same variates were tested for observations taken during the six summer months and found to have approximately the same correlations as for winter. Table 13 gives the results obtained for the summer season.

The correlation between the past 3-day temperature change and the following 3-day height tendency (X_3 and X_4) for all winter reports was quite low. The apparent poor relationship between 500 mb temperature changes and the type of advection at higher levels discouraged further investigation along this line. The results of this correlation are presented in Table 11.

Haurwitz [4], who was working with symmetry points for long range forecasting, came to the following conclusion:

> The phenomenon of symmetry occurs often enough to be utilized in forecasting if a symmetry could be recognized upon its arrival

However, he goes on to point out that since symmetry shows little tendency to persist, it cannot be utilized for forecasting by the time it is noticed in a pressure graph.

The good correlations obtained for 36-hour and 3-day tendencies at times of trough and ridge passages are, in actuality, measures of how close these troughs and ridges are to being symmetrical. The results of the investigation of height tendencies carried out in this study bear out both of Haurwitz' two conflicting statements.

It is possible to use symmetry considerations at Columbia, Missouri for forecast periods of 36 hours, although this may not be true for stations with a different geographical location. These symmetry characteristics weaken appreciably, however, for forecast periods of 3 days.

In conclusion, the regression equations derived for 36-hour and 3-day forecast intervals in the vicinity of troughs and ridges are both useable forecast tools near Columbia. These equations are listed in Tables 8 and 9.

2. Relationships Between Sea Level and 500 mb Waves.

In order to facilitate the visualization of some of the relationships between sea level and 500 mb waves, histograms of the data compiled in Tables 2 through 7 were constructed for certain selected sea level semi-periods. The six sea level semi-periods chosen for study (0.5 through 2.5 days and 3.5 days) represent 85 out of the 90 half-waves investigated in this paper.

The histograms drawn for each of the selected semi-periods are:

(1) Frequencies of the semi-period of the corresponding 500 mb half-waves divided into classes with intervals of one-half day.

(2) Frequencies of lag divided into classes with intervals of 6 hours.

(3) Frequencies of sea level range divided into three classes:

a. 0 to 15 mb (weak waves).

b. 15 to 30 mb (moderate waves).

c. Over 30 mb (strong waves).

(4) Frequencies of 500 mb range divided into three classes:

a. 0 to 200 feet (weak waves).

b. 200 to 600 feet (moderate waves).

c. Over 600 feet (strong waves).

(5) Frequencies observed by months.

These histograms are shown in Figures 1 and 2.

From these histograms a few qualitative forecast aids can be formulated:

(1) There is a tendency for sea level and 500 mb half-waves to have the same semi-periods. However, the maximum number of 500 mb semi-periods was observed to occur at 1.0 days, while the maximum for sea level half-waves occurred at 1.5 days. The average semi-period for waves at the two levels was almost the same, as would be expected. Evidently several short waves at 500 mb are followed by an unusually long one to get the wave trains at the two levels back in phase. Table 14 shows the number of observations of each semi-period.

(2) The average lag between 500 mb and sea level waves is approximately + 12 hours (sea level wave leads the 500 mb wave).

(3) As a general rule, the range increases with increasing sea level semi-period. This is true at both sea level and 500 mb, but more so at 500 mb. The correlation between sea level and 500 mb range for the 31 sea level semi-periods of 1.5 days was found to be only 0.23.

(4) The division of sea level semi-periods by months for the winter season studied appears to be random.

Summarizing, this investigation determined that, although certain periodicities can be detected, it is difficult, if not impossible, to forecast them. Furthermore, it is just as difficult to forecast how long

one particular period will persist. It was found that the average period for both sea level and 500 mb waves at Columbia during the winter studied was 3.4 days. This period is in good agreement with the 3-day period used in 'weather type' forecasting but cannot be used for accurate day to day 500 mb prognostication.

TABLE 8

Means

$\overline{X}_2 = -1.0536$ $\qquad$ $\overline{X}_6 = -0.8571$ $\qquad$ $\overline{X}_7 = 0.8036$

Standard Deviations

$\sigma x_2 = 4.4658$ $\qquad$ $\sigma x_6 = 4.9513$ $\qquad$ $\sigma x_7 = 4.8528$

Simple Correlation Statistics

$r_{26} = 0.7886$ $\qquad$ $X_2 = 0.7113\ X_6 - 0.4440$

$r_{27} = -0.7890$ $\qquad$ $X_7 = -0.8574\ X_2 - 0.0997$

$r_{67} = -0.8275$ $\qquad$ $X_7 = -0.8110\ X_6 \quad 0.1075$

Multiple Correlation Statistics

$r_{7.26} = 0.8556$ $\qquad$ $S_{7.26} = 2.5031$

$X_7 = -0.391\ X_2 - 0.533\ X_6 - 0.065$

Statistics of 36 - Hour Tendencies for Winter Troughs and Ridges (Number in Sample = 56)

TABLE 9

Means

$\overline{X}_1 = -0.3929$ $\quad$ $\overline{X}_2 = -1.0536$ $\quad$ $\overline{X}_3 = 1.1964$

Standard Deviations

$\sigma x_1 = 4.9449$ $\quad$ $\sigma x_2 = 4.3932$ $\quad$ $\sigma x_3 = 4.8529$

Simple Correlation Statistics

$r_{13} = -0.5675$	$X_3 = -0.5569X_1 \quad 0.9776$
$r_{12} = 0.7610$	$X_2 = 0.6761X_1 -0.7880$
$r_{23} = -0.7410$	$X_3 = -0.8185X_2 \quad 0.3340$

Multiple Correlation Statistics

$r_{3.12} = 0.7419$ $\qquad$ $S_{3.12} = 3.3936$

$X_3 = -0.058X_1 -0.725X_2 \quad 0.408$

Statistics of 3 - Day Tendencies for Winter Troughs and Ridges (Number in Sample = 56)

TABLE 10

Means

$\overline{X}_6 = -0.4140$ $\overline{X}_7 = 0.2167$

Standard Deviations

$\sigma x_6 = 3.7024$ $\sigma x_7 = 3.6542$

Simple Correlation Coeficient

$r_{67} = -0.3319$

Statistics of 36-Hour Tendencies for all 0300Z Data in Winter (Number in Sample = 157)

TABLE 11

Means

$\overline{X}_3 = -0.1300$ $\overline{X}_4 = 0.0030$

Standard Deviations

$\sigma x_3 = 4.1093$ $\sigma x_4 = 5.6098$

Simple Correlation Coefficient

$r_{34} = -0.2345$

Statistics of Past 3-Day Temperature Change
and Following 3-Day Height Tendency for Winter
(Number in Sample = 300)

TABLE 12

Means

$\bar{X}_1 = -0.1167$ $\bar{X}_2 = 0.0700$ $\bar{X}_3 = -0.1300$ $\bar{X}_5 = 1.5700$

Standard Deviations

$\sigma x_1 = 3.9870$ $\sigma x_2 = 3.4184$ $\sigma x_3 = 4.1093$ $\sigma x_5 = 4.4735$

Simple Correlation Statistics

$r_{13} = -0.3385$

$r_{32} = -0.5738$ $X_3 = -0.6898X_2 - 0.0818$

$r_{12} = 0.6172$ $X_2 = 0.5292X_1 \quad 0.1318$

$r_{25} = 0.7594$ $X_2 = 0.5803X_5 - 0.8411$

$r_{35} = -0.4215$

Multiple Correlation Statistics

$r_{3.12} = 0.5742$ $S_{3.12} = 3.3645$

$X_3 = 0.026X_1 - 0.696X_2 - 0.078$

$r_{3.25} = 0.5742$ $S_{3.25} = 3.3645$

$X_3 = 0.030X_5 - 0.718X_2 - 0.127$

Statistics of 3-Day Tendencies for all Winter Data
(Number in Sample = 300)

TABLE 13

Means

$\overline{X}_1 = 0.0259$ $\overline{X}_2 = -0.2529$ $\overline{X}_3 = 0.1063$ $\overline{X}_5 = 0.6351$

Standard Deviations

$\sigma x_1 = 2.3186$ $\sigma x_2 = 1.9429$ $\sigma x_3 = 2.3250$ $\sigma x_5 = 2.6623$

Simple Correlation Statistics

$r_{13} = -0.3118$

$r_{32} = -0.5475$ $X_3 = -0.6552X_2 - 0.0594$

$r_{12} = 0.6196$ $X_2 = 0.5192X_1 - 0.2663$

$r_{25} = 0.6732$ $X_2 = 0.4913X_5 - 0.5649$

$r_{35} = -0.3739$

Multiple Correlation Statistics

$r_{3.12} = 0.5485$ $S_{3.12} = 1.9439$

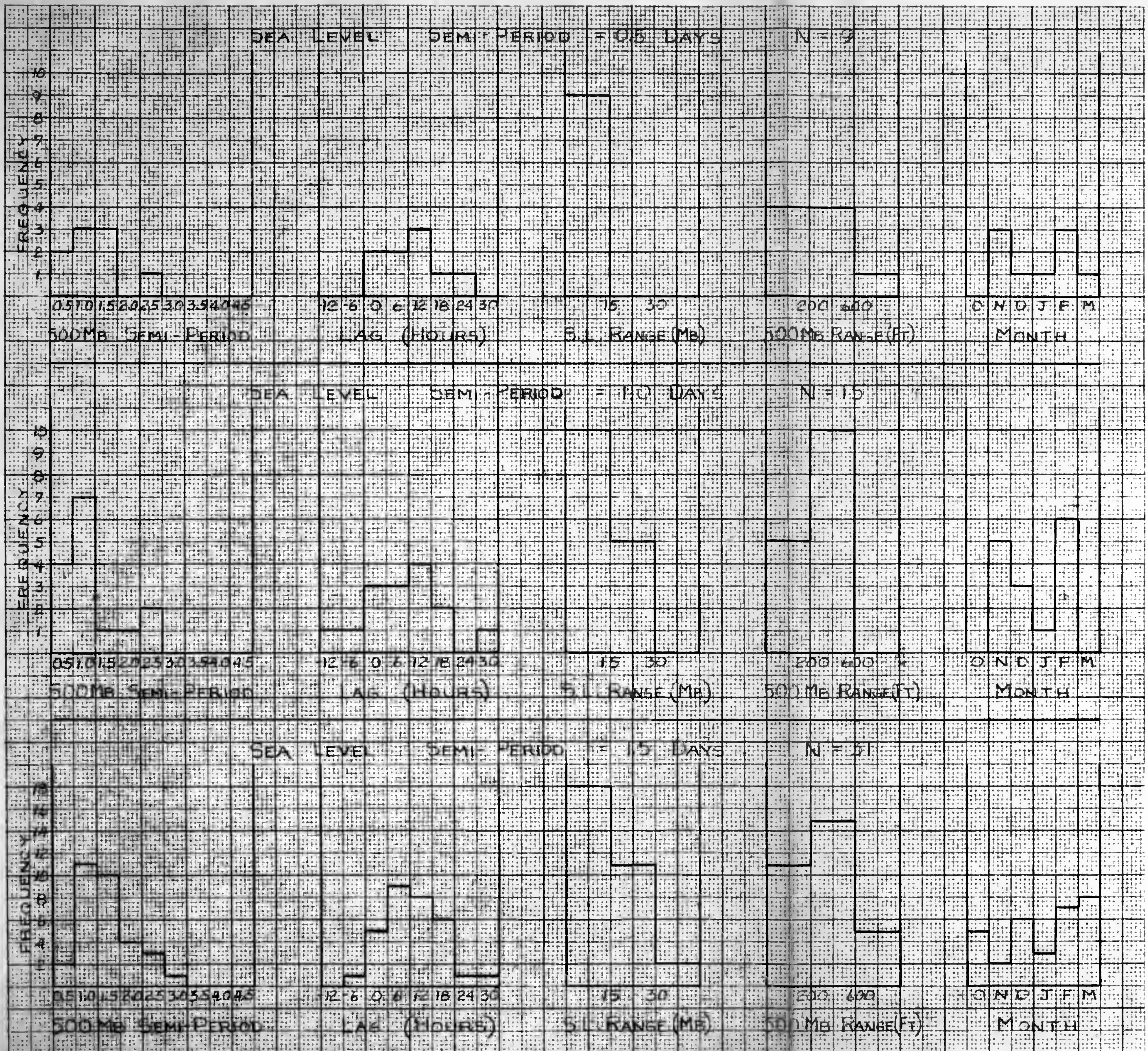
$X_3 = 0.045X_1 - 0.680X_2 - 0.069$

Statistics of 3-Day Tendencies for all Summer Data
(Number in Sample = 348)

TABLE 14

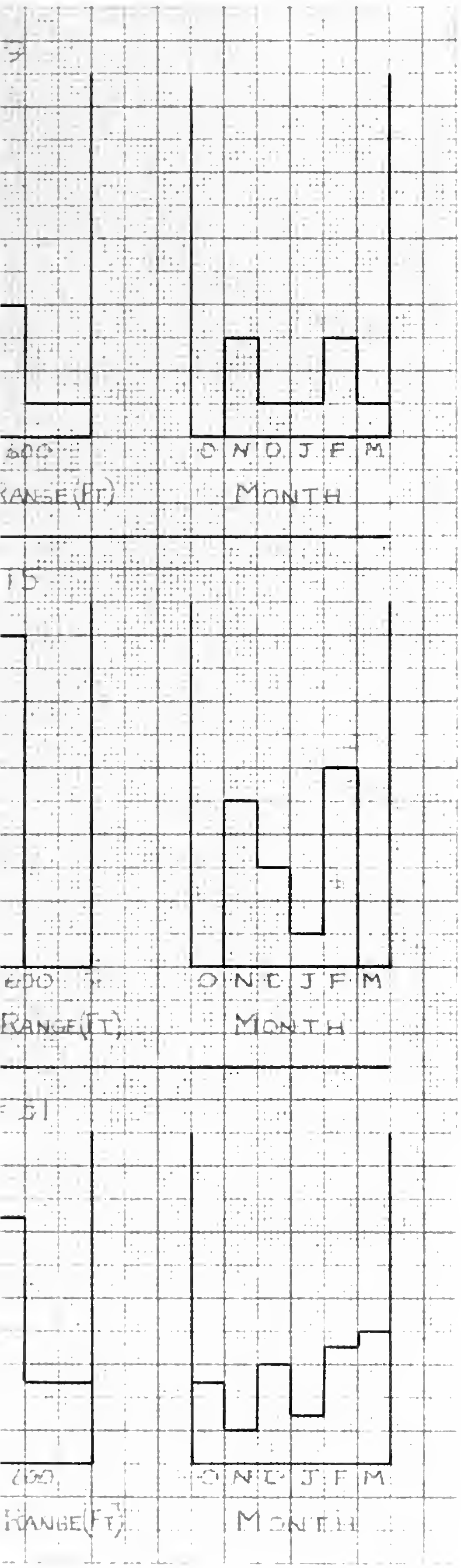
Semi-Period (Days)	Sea Level Frequency	500 mb Frequency
0.5	9	11
1.0	15	27
1.5	31	18
2.0	17	12
2.5	10	11
3.0	2	4
3.5	3	1
4.0	1	2
4.5	0	1
5.0	1	1
5.5	0	0
6.0	0	1
6.5	1	1
Total	90	90
Average	1.71	1.73

Number of Observed Semi-Periods at Sea Level and 500 mb



SEA LEVEL SEMI-PERIOD = 0.5 DAYS N = 9
FREQUENCY
500MB SEMI-PERIOD
LAG (HOURS)
S.L. RANGE (MB)
500MB RANGE (FT)
MONTH
SEA LEVEL SEMI-PERIOD = 1.0 DAYS N = 15
SEA LEVEL SEMI-PERIOD = 1.5 DAYS N = 51

Figure 1.



600
RANGE(FT)
O N D J F M
MONTH
600
RANGE(FT)
O N D J F M
MONTH
600
RANGE(FT)
O N D J F M
MONTH

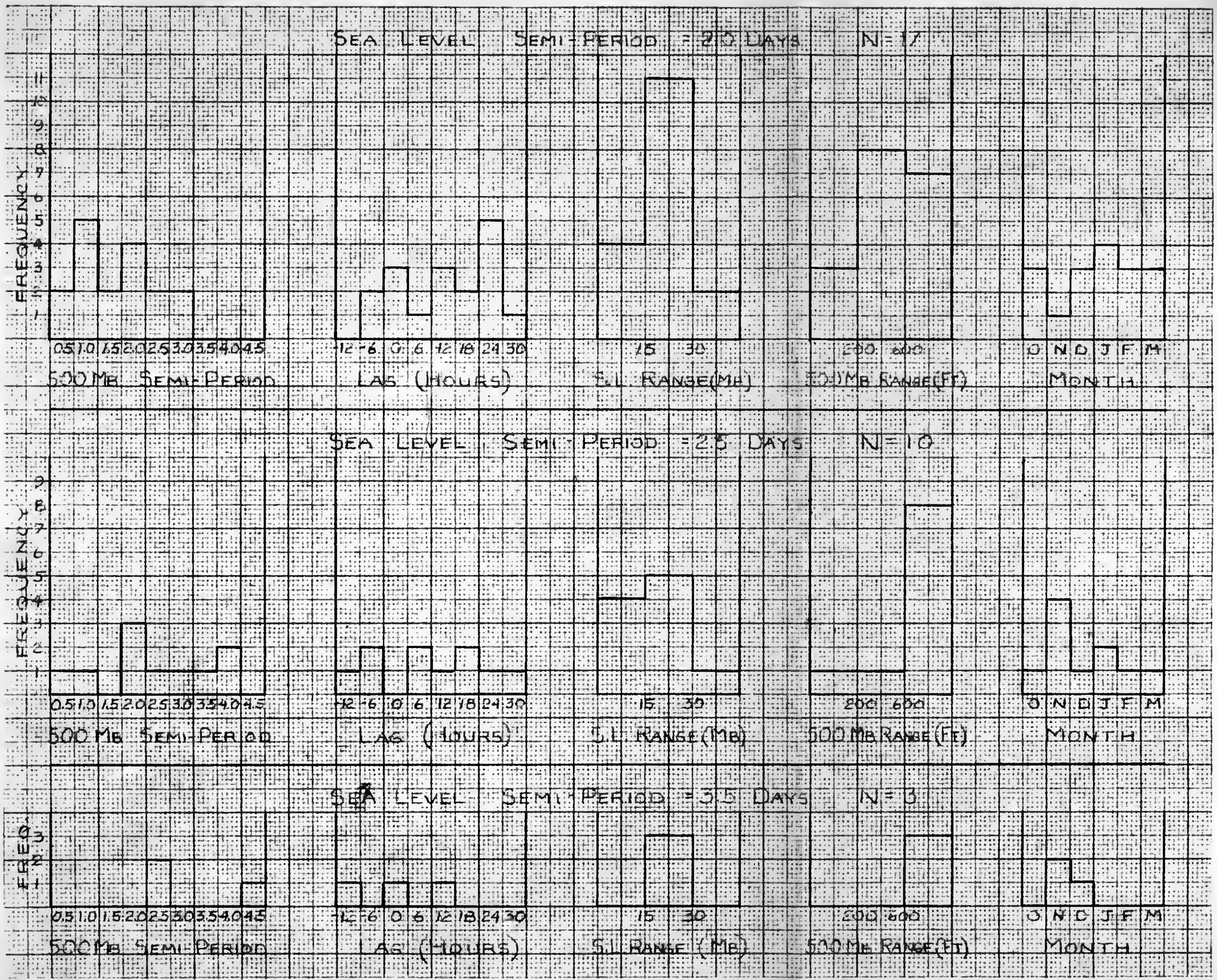
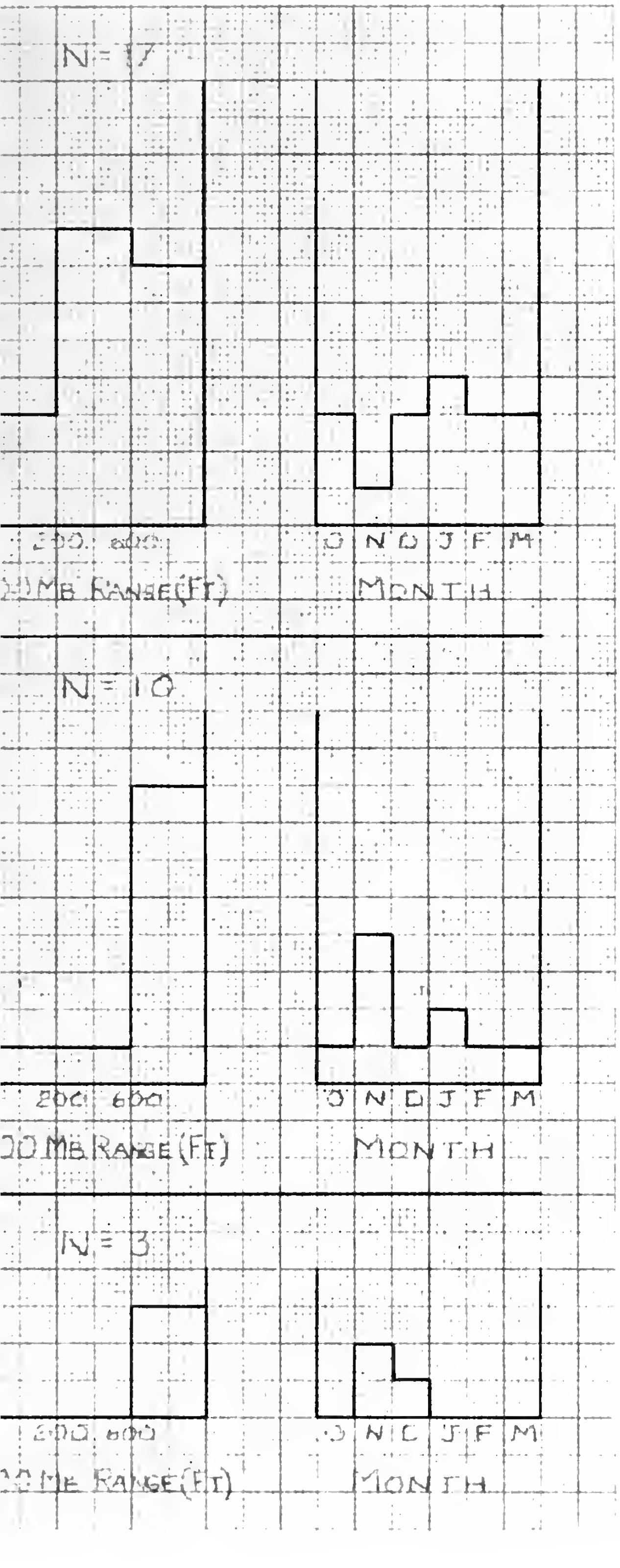

SEA LEVEL SEMI-PERIOD = 2.0 DAYS N = 17
FREQUENCY
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5
500 MB SEMI-PERIOD
-12 -6 0 6 12 18 24 30
LAG (HOURS)
15 30
S.L. RANGE (MB)
200 600
500 MB RANGE (FT)
O N D J F M
MONTH
SEA LEVEL SEMI-PERIOD = 2.5 DAYS N = 10
FREQUENCY
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5
500 MB SEMI-PERIOD
-12 -6 0 6 12 18 24 30
LAG (HOURS)
15 30
S.L. RANGE (MB)
200 600
500 MB RANGE (FT)
O N D J F M
MONTH
SEA LEVEL SEMI-PERIOD = 3.5 DAYS N = 3
FREQ.
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5
500 MB SEMI-PERIOD
-12 -6 0 6 12 18 24 30
LAG (HOURS)
15 30
S.L. RANGE (MB)
200 600
500 MB RANGE (FT)
O N D J F M
MONTH

Figure 2.


N = 17
200 600
MB RANGE (FT)
O N D J F M
MONTH
N = 10
200 600
MB RANGE (FT)
O N D J F M
MONTH
N = 3
200 600
MB RANGE (FT)
O N D J F M
MONTH

BIBLIOGRAPHY

1. Aime, E. A. and E. C. Johnson. Methods for the Preparation of Six-day Forecasts. Washington, D. C., U. S. Weather Bureau, November 1943.

2. Bellamy, J. C. The Use of Pressure Altitude and Altimeter Corrections in Meteorology. Journal Meteor. 1, 22, 1945.

3. Haurwitz, B. Final Report on the Use of Symmetry Points in the Pressure Curves for Long-range Forecasting. Weather Division, Headquarters Army Air Forces. March 1944 (Massachusetts Institute of Technology. Report No. 709).

4. Joint Meteorological Committee, Normal Weather Maps, Northern Hemisphere Upper Level. Washington, D. C., U. S. Weather Bureau, October, 1944.

5. Krick, I. P. A Dynamical Theory of the Atmospheric Circulation and its Use in Weather Forecasting, Meteor. Report, California Institute of Technology, February, 1942.

6. U. S. Weather Bureau, Daily Upper Air Bulletin. Washington, D. C., October 1948-September 1949.